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Towards a Large Field of View Archive for the European VLBI Network

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Abstract. Traditionally VLBI observations focus on a small patch of sky and image typically a few 100 mas around a bright source, which is often used to self-calibrate the data. High spectral and time resolution is needed to image a larger area, in principle up to the primary beam of the individual telescopes. The EVN MkIV data processor at JIVE is being upgraded to make such high resolution data its standard product. From the archive of high resolution data it will be possible to image many sources in each field of view around the original targets.

1. Introduction

The input data rate of a VLBI processor sets the total bandwidth that can be processed from each telescope. The output data rate determines how fine the correlation product can be sampled in frequency and time. The frequency resolution is important for various spectral line applications, but it also limits the field of view (FoV) that can be imaged before bandwidth smearing sets in. The temporal sampling also puts constraints on the FoV through time smearing, which scales with baseline length and distance from the field centre. The spectral resolution of a VLBI correlator is usually determined by the computing power built into its hardware, e.g. the number of available lags per baseline. The product over all available telescope pairs of spectral resolution and short visibility integration time combines into a large total output rate. There is generally a limit on the datarate at which this can be flushed out to a standard computing environment and saved on disk.

Both the spectral capabilities and the output bandwidth of the EVN data processor at JIVE are being upgraded. The first by introducing recirculation and the latter by the PCInt project. In this paper we discuss the scientific motivation and the future data handling of this system.

2. Scientific Justification

A VLBI dataset, if properly calibrated, has flat phase response, both in time and frequency, for the target position. Positional offsets from the phase centre introduce increasingly steep phase slopes. As long as these are properly sampled, the structure of sources away from the centre can be derived without time or bandwidth smearing. Both effects scale with baseline length (and are therefore particularly severe for VLBI); time smearing also scales with frequency (Wrobel 1995). In a traditional continuum VLBI experiment the integration time may be as long as 4s and typically 8×8 MHz bands are sampled, each with 16 spectral points. The resulting limits on the FoV can be seen in Table 1. Although the original recordings of a single VLBI experiment hold information over the whole field, typically only 10^3 out of 10^8 beams are imaged.

Table 1. The field of view set by integration time and spectral resolution .

Application	$N_{\rm sp}$	$t_{\rm int}$ [s]	Output [MB/s]	$\rm FoV_t$ [′]	$\rm FoV_{bw}$ [′]	$V_{\rm 12hr}$ [GB]
Traditional	128	4.000	0.02	0.70	0.82	1
Operational max	1024	0.500	1.50	5.57	6.59	63
Phase 0	2048	0.250	6.00	11.14	13.19	253
Full system	4096	0.031	96.00	89.11	26.36	4050

There are several astronomical applications that require larger fields of view. Galactic masers may extend over rather large areas, especially in star formation complexes. Gravitational lenses are another case where VLBI sources may extend over a large FoV. Moreover, studies of the faint radio source population may be done more efficiently when a large instantaneous field of view is available. A long integration at the full recording bandwidth can then be employed to study many weak sources simultaneously. As an example we consider the high resolution observations of radio sources in the Hubble Deep Field (HDF). It contains many radio-sources at low flux level over a large (by VLBI standards) field. Long integrations with the most sensitive telescopes are required to investigate their nature with VLBI. The Effelsberg beam encompasses an area much larger than the HDF and so in principle a single observation can be used to study the nature of each source with VLBI. This technique was explored with the EVN at 1.6 GHz and the VLBA correlator by Garrett et al. (2001). Even at this moderate resolution the FoV barely covers the HDF. VLBI detections for 3 sources were made at 150-350 μJy. Such studies will benefit greatly from the upgrades ongoing in the EVN, both in recording and correlator capacity.

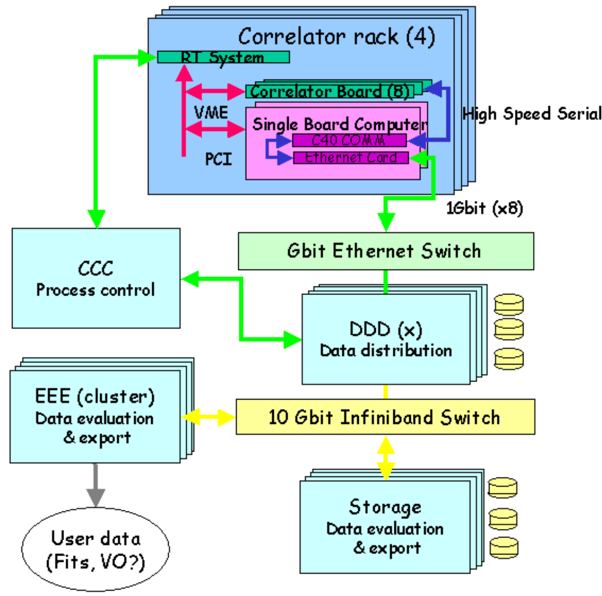

Figure 1. Outline of the data flow for the PCInt project

3. Dataflow

The EVN MkIV data processor correlates inputs from 16 stations simultaneously (Schilizzi et al. 2001). Each telescope input can handle up to 1 Gbit/s, from Mk4 tape or Mk5 disk playback. Its computing power is based on 32 boards, each equipped with 32 custom made chips, each producing 256 complex lags. This yields sufficient spectral capabilities to attribute 512 spectral channels to every baseline between 16 telescopes.

In its original configuration groups of 8 boards were controlled by an HP-RT system, which flushed the data out on 4 parallel 10Mb/s Ethernet lines. The first improvement to this system has recently been implemented by upgrading the system with 8 Single Board Computers (SBC), which handle the data from the HP-RT processors and have 100 Mb/s Ethernet to flush the data (Phase 0). In the final PCInt configuration each rack will have two Single Board Computers running Linux, which read the data from DSP powered serial ports. A total of 8×1 GB/s Ethernet connections are then available to flush out the data. The software is set up in such a way that the data can be handled in parallel by a set of workstations that write the data to an array of disks with fast access. This is necessary to overcome another possible bottleneck: disk access. The architecture can be seen in Figure 1.

In table 1 the Field of View (FoV) limits set by the bandwidth sampling (bw) and time smearing (t) in various stages of the project are shown. The calculations have been performed for a rather modest VLBI recording at 18cm on 8 EVN antennas with a total bandwidth of 64 MHz (2 bit sampled). The primary beam of a 25m telescope measures 27'. The requirements become even more severe at higher spatial resolution (global baselines, or higher frequency).

In the original system the data is first collected in raw correlator format. Downstream the data is transformed into an aips++ MeasurementSet. After local calibration and data quality control, FITS files are written. An archive of user products and diagnostic plots is on-line through a web interface[1]. Initially the data is password protected while the PI has the proprietary right.

With PCInt the data streams will increase, but similar operations on the data are still necessary. Data quality evaluation and internal calibration must be performed promptly. We are investigating whether this inspection can be performed without a physical copy of the data to aips++ internal format. While the output data will be at full resolution, the PI may receive the data at a coarser resolution, one that is optimal for the scientific goal of his study. In a similar way the interface to the archive will allow users to make a selection and create a dataset at a lower resolution, possibly by averaging for a new target position. This operation will be ported to a parallel processing environment, in order to make such products available in an almost interactive manner.

Through pipeline processing, JIVE is already providing preliminary calibration for every dataset. In order to accommodate this service for the data archive product, the calibration data must be closely integrated. Special care will be required for the calibration of data with a new field centre. In addition, the projected output data rate yields datasets of such large sizes that the astronomer will probably require tailor-made software and dedicated hardware to process them. Solutions for these issues are being investigated and will involve parallel computing. It is possible that wide field of view VLBI images will be made as an integral part of the data processor product. Such a solution would fit in with the Virtual Observatory paradigm.

After the successful completion of the so-called phase 0 project (Nov 2003), the European VLBI Network welcomes proposals that use the full correlator at 0.25s read-out (6MB/s). The data flow and software for the next phase are being tested and more capacity upgrades are expected in 2004. Then there will be a focus on the hardware and software to process all data at the maximum resolution and compute the data product from the archive using parallel processing. This effort has recently required funding from the EU for 2004-2007.

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[1]http://www.jive.nl/archive/scripts/listarch.php